AD-A100 715 MATERIALS RESEARCH LABS ASCOT VALE (AUSTRALIA) F/G 20/1
THE DEEP OCEAN SOUND CHANNEL IN AREAS AROUND AUSTRALIA,(U)
OCT 80 D J WHELAN
UNCLASSIFIED MRL-R-788 NL

1 OF 1
AD A
100715

END
DATE
FILMED
7-81
DTIC

MRL-R-788 LEVEL II (12) AR-002-368

AUSTRALIA

AD A100715

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

MATERIALS RESEARCH LABORATORIES

MELBOURNE, VICTORIA

REPORT

MRL-R-788

THE DEEP OCEAN SOUND CHANNEL IN AREAS AROUND AUSTRALIA

Daniel J. Whelan

Approved for Public Release

81 6 29 019

OCTOBER, 1980

DEPARTMENT OF DEFENCE

MATERIALS RESEARCH LABORATORIES

REPORT

MRL-R-788

THE DEEP OCEAN SOUND CHANNEL IN AREAS AROUND AUSTRALIA

Daniel J. Whelan

ABSTRACT

The physicochemical data collected on MRL cruises OP7803 (Southern Indian Ocean), OP7704 (Coral Sea) and OP7505 (Around Tasmania) have been used to determine the acoustical properties predicted for the deep ocean sound channel (SOFAR axis) in these bodies of water.

POSTAL ADDRESS: Chief Superintendent, Materials Research Laboratories
P.O. Box 50, Ascot Vale, Victoria 3032, Australia

DOCUMENT CONTROL DATA SHEET

Security classification of this page: UNCLASSIFIED

1. DOCUMENT NUMBERS: a. AR Number: AR-002-368 b. Series & Number: REPORT MRL-R-788 c. Report Number: MRL-R-788	2. SECURITY CLASSIFICATION: a. Complete document: UNCLASSIFIED b. Title in isolation: UNCLASSIFIED c. Abstract in isolation: UNCLASSIFIED

3. TITLE:

THE DEEP OCEAN SOUND CHANNEL IN AREAS AROUND AUSTRALIA

4. PERSONAL AUTHOR(S): WHELAN, Daniel J.	5. DOCUMENT DATE: OCTOBER, 1980 6. TYPE OF REPORT & PERIOD COVERED:
7. CORPORATE AUTHOR(S): Materials Research Laboratories	8. REFERENCE NUMBERS: a. Task: DST 78/150 b. Sponsoring Agency: 9. COST CODE: 284420
10. IMPRINT (Publishing establishment) Materials Research Laboratories P.O. Box 50, Ascot Vale, Vic. 3032 OCTOBER, 1980	11. COMPUTER PROGRAMME(S) (Title(s) and language(s)).

12. RELEASE LIMITATIONS (of the document):

Approved for Public Release

12-0. OVERSEAS: N.O. [ ] P.R. [1] A [ ] B [ ] C [ ] D [ ] E [ ]

13. ANNOUNCEMENT LIMITATIONS (of the information on this page):

No limitation

14. DESCRIPTORS: 630 Sofar Underwater sound transmission
645 Acoustic absorption Acoustic attenuation Sea water
Southern Pacific Ocean Southern Indian Ocean

15. COSATI CODES: 0704 2001

16. ABSTRACT (if this is security classified, the announcement of this report will be similarly classified):

The physicochemical data collected on MRL cruises OP7803 (Southern Indian Ocean), OP7704 (Coral Sea) and OP7505 (Around Tasmania) have been used to determine the acoustical properties predicted for the dcep ocean sound channel (SOFAR axis) in these bodies of water.

CONTENTS

* * *

THE DEEP OCEAN SOUND CHANNEL IN AREAS AROUND AUSTRALIA

1. INTRODUCTION

Over the past five years, the Marine Environment Group of the Materials Research Laboratories participated in a series of oceanographic cruises (Table 1) in order to characterise variations in the physical and chemical environment of the ocean waters around Australia. Reports summarising results from four such cruises have recently been published [1-4].

During each cruise, a number of stations was occupied and, at each station, water samples were taken and subsequently analysed for variations with depth of temperature, salinity, pH and alkalinity, dissolved oxygen, metal ion concentrations, etc. From the data thus accumulated, various calculations can be made on the expected dynamic properties of the ocean mass including profiles of the velocity of sound [5], its absorption and transmission in sea water [6-9], water transport and circulation [10] and the stratification of waters within the ocean [11].

The purpose of this paper is to identify the prevailing deep ocean sound channels or SOFAR-axes [8] in various bodies of water around Australia from hydrographic data and then to use the oceanographic data to predict acoustical properties in these sound channels [9].

2. SOUND CHANNELS

An introduction to the concept of a sound channel has already been given [8], where these channels originate from the trapping of acoustical energy by refraction along axes where the sound velocity reaches a minimum.

From the literature, it appears that a major part of any long-range undersea surveillance capability depends on one's ability to locate the position of submerged submarines by sound fixing and ranging (SOFAR) techniques [12,13] where the accuracy of a 'fix' depends upon the use of a correct sound speed in the 'deep ocean sound (SOFAR) channel' [13]. The actual depth at which this channel occurs is determined by several oceanographic factors, all determined by the nature and origin of the water masses around a particular location. In mid-latitudes, it typically occurs near 1000 m.

As mentioned in the introduction, the speed of sound in sea water can be calculated very accurately from a knowledge of the depth, salinity and temperature of the sea [5] and, from this, one can then deduce not only the depth of the SOFAR channel but also how it varies with location in a particular area. This is illustrated in Table 2, from data collected in the Indian Ocean by MRL scientists in March 1978 [2]. It also varies from ocean to ocean (Table 3).

While active and passive sonars operate in different parts of the acoustical spectrum, their performance is effected somewhat by the process of sound absorption which occurs as a result of chemical relaxation phenomena [8,9] and is the major contributor to the total attenuation observed in the deep ocean sound channel [14,15].

It has been established that the low frequency absorption of sonar energy (0.4-2 kHz) is primarily due to the presence of borate and complexed carbonate species in solution [6,16,17] while the intermediate frequency (10-500 kHz) absorption arises from complexed magnesium sulphate ion pairs in sea water [7]. The magnitude of these absorption processes and the relaxational frequencies about which they are centred depend on ionic concentrations, temperature, depth, pH and alkalinity, all chemical variables measured on MRL cruises.

3. ACOUSTICAL RELAXATION IN SEA WATER

The overall sound absorption in sea water as a result of physicochemical relaxation processes, α, is simply the sum of contributions of these individual processes, namely

$$\alpha = \sum_i \alpha_i \tag{1}$$

For a single relaxation process, the dependence of the sound absorption coefficient, α_i, on the observing frequency, f, is given by

$$\alpha_i = K_i \frac{f_{ri} \; f^2}{f_{ri}^2 + f^2} \tag{2}$$

where f_{ri} is the relaxation frequency of the medium. K_i is also a characteristic of the medium and is a measure of its compressibility under the influence of the perturbing process.

When $f = f_{ri}$,

$$\alpha_i = \alpha_{ri} = \tfrac{1}{2} K_i . f_{ri} \tag{3}$$

If v is the velocity of sound in the medium

$$v = f_{ri} \lambda_{ri}$$

where λ_{ri} is the wavelength of the acoustic wave corresponding to the relaxation frequency, f_{ri}.

Hence, $$\alpha_{ri} \lambda_{ri} = \tfrac{1}{2} K_i v$$

$$\therefore \quad K_i = \frac{2\alpha_{ri} \lambda_{ri}}{v}$$

and

$$\alpha_i = \frac{2\alpha_{ri} \lambda_{ri}}{v} \; \frac{f_{ri} \; f^2}{f_{ri}^2 + f^2} \tag{4}$$

The commonly-used unit of the absorption coefficient, α_i, is the decibel per kilometre, dB km^{-1}.

It is common to discuss oceanographic acoustical data both in terms of 'the excess absorption per wavelength at the relaxation frequency' or 'excess absorption factor', $\alpha_{ri} \lambda_{ri}$, which is also written $(\alpha\lambda)_{ri}$, and in terms of f_{ri}, the relaxation frequency.

The terms $(\alpha\lambda)_{ri}$ are particularly useful as they give a sensitive method for deducing the relative intensities of different absorption

processes, (Table 4). $(\alpha\lambda)_{ri}$ are usually expressed in units of decibel (dB) or neper (Np) [9].

Laboratory and field experiments have established that the operational variables in eq. 4, namely K_i and f_{ri}, do vary from ocean to ocean [6,18-20]. The major contribution to the low frequency absorption in the ocean at pH 7-8.5 comes from boric acid-borate interactions (Table 4), the magnitude of this contribution being some 10-fold greater than that from magnesium carbonate ion pair formation [16,21] at 1 kHz.

Several expressions have been derived which relate the acoustical parameters in eq. 4 to oceanographic variables, the most recent and comprehensive being that of Schulkin and Marsh [9]. From a statistical analysis, they derived the following relationships :

$$(\alpha\lambda)_{r1} \times 10^4 = 2.69 \times 10^{0.69\mathrm{pH} - 6} \qquad (5)$$

and

$$f_{r1} = 6.1 \times \left(\frac{S}{35}\right)^{\frac{1}{2}} \times 10^{f_1(T)}\ \mathrm{kHz} \qquad (6)$$

where $f_1(T) = 3 - (1051/T)$, T being the temperature (degree K).

In eq. 5 and 6, the subscript 1 refers to the contribution from boric acid - borate interactions, in sea water of salinity, S, 33.5 - 40.5 ppt.

The magnesium-carbonate interaction (subscript 4) was first reported in 1979 [16] and is, at this juncture, best regarded as a refinement to the present situation. Its contribution to the overall absorption is summarised by the equations

$$(\alpha\lambda)_{r4} \times 10^4 = 2.25 \times 10^{\mathrm{pH}-9}\ \mathrm{dB} \qquad (7)$$

and

$$f_{r4} = 2.821 \times 10^{10-(2675/T)}\ \mathrm{kHz} \qquad (8)$$

These expressions, summarised by eq. 5-8, refer to conditions at 1 atm. pressure. The effect of pressure on the variables f_{r1}, f_{r4}, $(\alpha\lambda)_{r1}$ and $(\alpha\lambda)_{r4}$ have not been studied; however, if they follow trends observed in $MgSO_4$ relaxation [7], then the pressure effects will be of the order of ±10% at 100 bar [8,9], the approximate pressure at the deep ocean sound channel.

At intermediate frequencies (10-500 kHz), $MgSO_4$ ion pair relaxation (subscript 2) is the dominating sound absorption process [7]. The temperature dependence of f_{r2} of $MgSO_4$ in sea water over the range 2^o-30^oC at atmospheric pressure is given by

$$f_{r2} = 1.229 \times 10^{7-(1483/T)} \text{ kHz} \tag{9}$$

where T is in degree Kelvin.

At 25^oC, f_{r2} equals 131 kHz; at 4^oC, it equals 55 kHz.

The pressure dependence of f_{r2} in sea water, f_{r2} (p), is given approximately by the relation

$$f_{r2}(p) = f_{r2}(0) + 7.5 \times 10^{-2}p \text{ kHz} \tag{10}$$

where p is the pressure, bar [7].

At 4^oC and 100 bar pressure, f_{r2} will be *ca*. 62 kHz, a value very close to that determined semi-empirically in the SOFAR deep axis sound channel in the Atlantic Ocean, 64 kHz [7,22].

The excess absorption factor, $(\alpha\lambda)_{r2}$, in sea water varies with pressure [7] and would also appear to increase with increasing concentrations of Mg^{++} at sea water concentrations [7]; at sea level, at a Mg^{++} level of 1290 ppm

$$(\alpha\lambda)_{r2}\ [25^oC, 1 \text{ bar, sea water}] = 5.53 \times 10^{-4} \text{ dB} \tag{11}$$

and, in the deep axis sound channel,

$$(\alpha\lambda)_{r2}\ [4^oC, \overset{100}{\cancel{1}} \text{ bar, sea water}] = 5.09 \times 10^{-4} \text{ dB} \tag{12}$$

As mentioned earlier, $MgSO_4$ relaxation is the predominant absorption process over the frequency range 10-500 kHz. Beyond 500 kHz, the predominant absorption process is attributed to the response of water itself to pressure changes stimulated by the passage of acoustical energy [23]; the absorption coefficient due to this effect, α_3, is given by

$$\alpha_3 = 3.0 \times 10^{-4} f^2 \text{ dB km} \tag{13}$$

the magnitude of which changes by less than 1% at 100 bar relative to that at 1 bar pressure [23] at $4^{\circ}C$.

From a knowledge of oceanographic variables, one can calculate the absorption coefficient, α, from various α_i evaluated at a particular frequency and can use this information to refine sound fixing and ranging procedures, (Tables 4,5).

4. ACOUSTICAL ABSORPTION AT THE DEEP OCEAN SOUND CHANNEL : RESULTS AND DISCUSSION

4.1 *Occurrence of the Sound Channel*

As mentioned above, the deep ocean sound channel or SOFAR axis occurs at a depth where the sound velocity is a minimum, the acoustical energy being trapped within this channel by refraction to provide a duct suitable for the transmission and reception of undersea communications and intelligence [13,24].

Throughout this paper, sound speeds have been computed from observed oceanographic variables using an equation proposed by del Grosso and Mader [5] and, from a consideration of the resulting sound speed-depth profiles, the location of the deep ocean sound axes, where they exist, have been determined.

However, equations such as del Grosso and Mader's [5] are cumbersome, even though they do give accurate results. An over-simplified but enlightening sound speed equation, extensively used by Northrup and Colburn [13] and based on an equation proposed by Medwin [25], enables one to appreciate how the speed of sound in sea water depends on oceanographic parameters, viz.

$$v = 1449.14 + 4.57t + 1.4\,(S-35) + 0.016D \qquad (14)$$

where v is the speed of sound ($m\ sec^{-1}$) at a depth D (metre) in sea water $t^{\circ}C$ and salinity S (parts per thousand). From this equation, in isohaline water, one derives, for comparative purposes, the differential equations

$$\frac{\partial v}{\partial t} \simeq 4.6\ m\ sec^{-1}\ (C^{\circ})^{-1} \qquad (15)$$

and

$$\frac{\partial v}{\partial D} \simeq 0.016\ m\ sec^{-1}\ m^{-1} \qquad (16)$$

Near the SOFAR axis, over a range of 100 m in mid-latitudes, the temperature drop may be of the order of 0.8°C. From these equations, one can deduce that changes in the sound velocity will be influenced mainly by changes in the temperature-depth profile near the depth where the velocity is approaching its velocity minimum.

Typical results from MRL Cruises are given in Tables 6-8. Results from the two New Zealand Cruises are still being processed and cannot be incorporated in this report.

4.2 The Deep Ocean Sound Channel : Indian Ocean Cruise OP7803

In Figs 1 and 2, a detailed map of the area traversed in the Indian Ocean Cruise OP7803 in March 1978 is given. This map is part of a more comprehensive map of the southern portion of the Indian Ocean [26]. However, the area studied may possibly be considered characteristic of the ocean as a whole, in as far as the Indian Ocean contains many uninterrupted expanses of deep water, spread over its entire southerly domain between 35°S and the equator [27].

The components of the temperature/salinity/depth/pH profile of the deep ocean sound channel in the Indian Ocean, as it occurred in March 1978, between 9°-30°S and 105°-112°E, are given in Table 9. The only station for which the sound channel appeared to reside below 1000 m was Station F [2]; at Station F, however, the results obtained were unusual as a plot of temperature-vs-depth between 800 and 1200 m at this station was not consistent with plots made with data collected elsewhere on this and other cruises [1,2]. Neglecting the data from this one station, the physicochemical variables over this area can be averaged, thus :

Sound channel axis	940 m
Temperature	5.1°C
Salinity	34.6 ppt
pH	7.84
Sound speed	1486 m sec^{-1}

and the acoustical parameters relating to the absorption of sound at the SOFAR axis can be calculated to yield

$$(\alpha\lambda)_{r1} \times 10^4 = 0.69 \text{ dB}$$

$$f_{r1} = 1.02 \text{ kHz}$$

$$(\alpha\lambda)_{r4} \times 10^4 = 0.15_6 \text{ dB}$$

$$f_{r4} = 6.8_9 \text{ kHz}$$

$$(\alpha\lambda)_{r2} \times 10^4 = 4.88 \text{ dB}$$

(assuming av. Mg conc. 12.34 $\times$ $10^5 \mu g\ l^{-1}$, Ref. 2)

$$f_{r2} = 64.7 \text{ kHz}$$

$$\alpha_3 = 3.0 \quad 10^{-4} f^2 \text{ dB km}^{-1}$$

4.3 The Deep Ocean Sound Channel : Coral Sea Cruise OP7704

A simplified map of the area between 22°S-33°S, 150°E-166°E traversed in the MRL Coral Sea Cruise OP7704 in April-May 1977 is given in Fig. 3. This area has been charted in considerable detail and the results of this charting have been incorporated in the International Chart AUS 4602 [27]. The results from this cruise have been tabulated in Ref. 1 and the characteristics of the deep ocean sound channel have been summarised in Table 10.

Previous work in the area has been reported by Scully-Power, France and Lockerman [29-32] from the Royal Australian Navy Research Laboratory; that portion of their work, relevant to MRL interests being considered here, relates to work carried out in May 1968 in the area 12°S-20°S, 150°E-165°E, just north of the area traversed by the MRL Cruise, OP7704 [28].

From the data reported in the RANRL experiments, it was calculated [5,29-32] that, in the area in which they worked, the deep ocean sound channel occurred at an average depth of 885 ± 50 m, in water of unusually constant salinity 34.5 ± 0.03 ppt, the average temperature of the water in this sound channel being 4.3 ± 0.4 degree C and the average sound speed *ca.* 1482 ± 2 m sec^{-1}.

In contrast, there were only three stations on the MRL Cruise where the second channel occurred at depths less than 1000 m - namely, at stations H, K and L (Table 10). The averaged sound channel characteristics at these three stations were: depth 950 ± 30 m, temperature 5.2 ± 0.1 degree C, salinity 34.4 ± 0.1 ppt, pH 7.90 and sound speed 1486 m sec^{-1}. All three of these stations occurred near New Caledonia, just north of the parallel of latitude 23°S. Along the north-east path of the MRL Cruise from Sydney to Noumea (27 April 1977 - 2 May 1977), the deep ocean sound channel was calculated to reside much deeper, *ca.* 1270 ± 130 m, in colder water at an average temperature 4.2 ± 0.5 degree C but at a similar salinity 34.5 ± 0.1 ppt and pH 7.88 ± 0.02.

Be that as it may, the calculated sound speed in each section was remarkably constant, 1487 ± 1 m sec^{-1}, reflecting the compensating effects of increased pressure and decreased temperature on the calculated velocity of sound.

From these data, one can predict the acoustical properties of the deep ocean sound channel along this north-east path, thus :

$$(\alpha\lambda)_{r1} \times 10^4 = 0.73_6 \text{ dB}$$

$$f_{r1} = 0.98 \text{ kHz}$$

$$(\alpha\lambda)_{r4} \times 10^4 = 0.17 \text{ dB}$$

$$f_{r4} = 6.4 \text{ kHz}$$

$$(\alpha\lambda)_{r2} \times 10^4 = 4.82 \text{ dB}$$

(assuming av. Mg conc. $12.23 \times 10^5\ \mu g\ l^{-1}$, Ref. 1)

$$f_{r2} = 64.9 \text{ kHz}$$

Note: Dr Marshall Hall from the Royal Australian Navy Research Laboratory drew our attention to the fact that Scully-Power and his coworkers [29-32] calculated sound speeds using Wilson's formula, whereas in this work, the author used an alternative formula derived by del Grosso and Mader [5]. It has been the author's experience that the two formulae give identical results when calculations are rounded off at the fourth significant figure.

4.4 The Deep Ocean Sound Channel : Around Tasmania, Cruise OP7507 (July 1975)

The existence of a deep ocean sound channel presupposes that sound will be trapped in a duct formed by successive upwards and downwards refraction of acoustical energy [8,33]; in the waters around Australia, physical modelling suggests that this duct will form at depths near 1000 m where the sound velocity reaches its minimum value. Because 'bottom losses' can and do occur [34,35], it follows that the depth of the water mass needed to sustain a deep ocean sound channel should be some arbitrarily defined 200-300 m deeper than the depth at which the calculated minimum velocity of sound occurs - perhaps as deep as 1600-1800 m.

Much of MRL's interest on the Cruise OP7507 necessitated water sampling in shallow waters [3] over the area traversed (Fig. 4,5). However, some deep water sampling did also occur and, from this work, the channel characteristics at five locations around Tasmania could be determined (Table 11).

The averaged values of the oceanographic variables describing the deep ocean sound channel are: average depth 1260 m, temperature 4.0°C, salinity 34.54 ppt, pH 7.95 and sound velocity 1486 m sec^{-1} (July 1975), from which the following acoustical properties can be calculated :

$$(\alpha\lambda)_{r1} \times 10^4 = 0.84 \text{ dB}$$

$$f_{r1} = 0.98 \text{ kHz}$$

$$(\alpha\lambda)_{r4} \times 10^4 = 0.20 \text{ dB}$$

$$f_{r4} = 6.3 \text{ kHz}$$

$$(\alpha\lambda)_{r2} \times 10^4 = 4.97 \text{ dB}$$

(assuming av. Mg conc. $12.62 \times 10^5 \, \mu g \, l^{-1}$, Ref. 3)

$$f_{r2} = 64.3 \text{ kHz}$$

4.5 Conclusion

In Table 12, the acoustical properties associated with the absorption of sound in sea water as predicted for the deep ocean sound channels located in certain areas around Australia have been listed. These acoustical properties arise from the influence of chemical interactions in sea water and, as such, they vary with the composition, chemical concentrations and the physicochemical properties of the ocean, probably from year to year and season to season [11,27]. Nowhere is this borne out more startlingly than in our results from the Coral Sea Cruise where the depth of the sound channel over Stations H, J and K (950 m) occurs in much shallower water than that for Stations A to G (1270 m).

Be that as it may, the physicochemical properties, temperature, salinity and pH, do not vary as much in the deep ocean sound channel as they do near the sea's surface and hence the acoustical properties of the deep ocean sound channel should be quite predictable.

Whether the differences are significant in relation to the performance of sonar detector systems remains to be seen. One can envisage that, at low frequencies (<2 kHz), the variations of $(\alpha\lambda)_{r1}$ with ocean properties in the SOFAR channel could be related to ultimate sensor performance in long-range surveillance [36].

5. ACKNOWLEDGEMENTS

The author wishes to acknowledge the efforts of his colleagues and coworkers in the Marine Environment Group of our establishment who participated in the various cruise programs and assisted in the laboratory work. He also thanks Dr Marshal Hall (Royal Australian Navy Research Laboratory) for his helpful criticism and advice in the preparation of this report.

6. REFERENCES

1. Marine Environment Group. (1978). "Oceanographic Observations in the Coral Sea, May 1977" (Coordinating author: R.W. Pettis). *MRL Physical Chemistry Divisional Report* PCD 78/2.

2. Marine Environment Group. (1980). "Oceanographic Observations in the Indian Ocean, March 1978. A Chemical Survey" (Coordinating authors: R.W. Pettis and D.J. Whelan). *Materials Research Laboratories Report* MRL-R-792.

3.(a) de Forest, A., Pettis, R.W. and Fabris, G. (1978). "Analytical Acceptability of Trace Metal Levels found in Oceanic Waters around Tasmania". *Aust. J. Mar. Freshwater Res.*, 29, 193-204.

(b) Bishop, J.H. and Pettis, R.W. (Materials Research Laboratories, Physical Chemistry Division), unpublished data.

4. de Forest, A., Murphy, S.P. and Pettis, R.W. (1978). "Heavy Metals in Sediments from the Central New South Wales Coastal Region". *Aust. J. Mar. Freshwater Res.*, 29, 777-785.

5. del Grosso, V.A. and Mader, C.W. (1972). "Speed of Sound in Seawater Samples". *J. Acoust. Soc. Am.*, 52, 961-974.

6. Schulkin, M. and Marsh, H.W. (1978). "Low Frequency Sound Absorption in the Ocean". *J. Acoust. Soc. Am.*, 63, 43-48.

7. Whelan, D.J. (1980). "Intermediate Frequency Sound Absorption in the Deep Ocean : the Role of Magnesium Sulphate". *Materials Research Laboratories Report* MRL-R-777.

8. Whelan, D.J. (1980). "A Review of Some Physical and Chemical Factors affecting the Attenuation of Low Frequency Sound in Seawater". *Materials Research Laboratories Report* MRL-R-782.

9. Whelan, D.J. (1980). "Approaches to a Quantitative Analytical Description of Low Frequency Sound Absorption in Seawater". *Materials Research Laboratories Report* MRL-R-791.

10. Mamorino, G.O. and Caldwell, D.R. (1976). "Heat and Salt Transport through a Diffusive Thermohaline Interface". *Deep Sea Res.*, 23, 59-67.

11.(a) Reid, J.L. (1977). "Some Thoughts on the Dependence of Sound Speed and the Scattering Layers upon Ocean Circulation" in *Oceanic Sound Scattering Prediction* (eds. N.R. Andersen and B.J. Zahuranec), 859 pp., pp.15-64. Plenum Press.

(b) Reid, J.L. and Lynn, R.J. (1971). "On the Influence of the Norwegian-Greenland and Weddell Seas upon the Bottom Waters of the Indian and Pacific Oceans". *Deep Sea Res.*, 18, 1063-1088.

(c) Reid, J.L. and Arthur, R.S. (1975). "Interpretation of Maps of Geopotential Anomaly for the Deep Pacific Ocean". *J. Marine Res.*, 33, (Suppl.), 37-52.

12. Urick, R.J. (1975). "Principles of Underwater Sound". Section 6.2. New York: McGraw Hill.

13. Northrop, J. and Colborn, J.G. (1974). "Sofar Channel Axial Sound Speed and Depth in the Atlantic Ocean". *J. Geophys. Res.*, 79, 5633-5641.

14. Thorp, W.H. (1965). "Deep Ocean Sound Attenuation in the Sub- and Low-Kilohertz Region". *J. Acoust. Soc. Am.*, 38, 648-654.

15. Skretting, A. and Leroy, C. (1971). "Sound Attenuation between 200 Hz and 10 kHz". *J. Acoust. Soc. Am.*, 49, 276-282.

16. Mellen, R.H., Browning, D.G. and Simmons, V.P. (1979). "Acoustic Absorption in Seawater : A Third Chemical Relaxation". *J. Acoust. Soc. Am.*, 65, 923-925.

17. Kibblewhite, A.C., Bedford, N.R. and Mitchell, S.K. (1977). "Regional Dependence of Low Frequency Attenuation in the North Pacific Ocean". *J. Acoust. Soc. Am.*, 61, 1199-1177.

18. Mellen, R.H. and Browning, D.G. (1977). "Variability of Low Frequency Sound Absorption in the Ocean : pH Dependence". *J. Acoust. Soc. Am.*, 61, 704-706.

19. Lovett, J.R. (1979). "Geographic Variation of Low Frequency Sound Absorption in the Pacific Ocean". *J. Acoust. Soc. Am.*, 65, 253-254.

20. Fisher, F.H. and Simmons, V.P. (1977). "Sound Absorption in Seawater". *J. Acoust. Soc. Am.*, 62, 558-564.

21. Mellen, R.H., Browning, D.G. and Simmons, V.P. (1979). "Acoustic Absorption by $MgCO_3$ Ion Pair Relaxation". *Nature 279*, 705-706.

22. Thorp, W.H. (1967). "Analytic Description of the Low Frequency Attenuation Coefficient in Seawater". *J. Acoust. Soc. Am.*, 42, 270.

23. Clay, C.S. and Medwin, H. (1977). "Acoustical Oceanography : Principles and Applications". 544 pp., esp pp.414-423. Wiley-Interscience.

24. Johnson, R.H. and Norris, R.A. (1968). "Geographic Variation of Sofar Speed and Axis Depth in the Pacific Ocean". *J. Geophys. Res.*, 73, 4695-4700.

25. Medwin, H. (1975). "Speed of Sound in Water : A Simple Equation for Realistic Parameters". *J. Acoust. Soc. Am.*, 58, 1318-1319.

26. The Hydrographer, Royal Australian Navy. (1975). "International Chart Series, Indian Ocean Southern Portion, Int. 70 (Aus 4070)", with small corrections.

27. Wyrtki, K. (1973). "Physical Oceanography of the Indian Ocean". In B. Zeitzschel and S.A. Gerlack, Editors, "The Biology of the Indian Ocean", pp.18-36. London: Chapman-Hall Ltd.

28. The Hydrographer, Royal Australian Navy. (1973). "International Chart Series, Southern Pacific Ocean. Tasman and Coral Seas, Australia to Northern New Zealand and Fiji, Int. 602 (Aus 4602)", with small corrections.

29. Scully-Power, P. and France, J.C. "Oceanographic Cruise : Coral Sea, May 1968". *Royal Australian Navy Research Laboratory Technical Memorandum*, March 1969, No. 2/69.

30. Scully-Power, P. "Oceanography of the Coral Sea : The Winter Regime". *Royal Australian Navy Research Laboratory Technical Note*, 1973, 13/73.

31. Scully-Power, P. "Oceanographic Cruise : Coral Sea, November-December 1966". *Royal Australian Navy Research Laboratory Technical Memorandum*, October 1969, No. 14/69.

32. Lockerman, R.C. and Scully-Power, P.D. "Temperature-Salinity Relationships and Associated Geotrophic Circulation and Sound Velocity Calculations for Two Seasons in the Western Coral Sea". *Royal Australian Navy Research Laboratory Technical Note*, 1968, No. 1/68.

33.(a) Reference 12, esp pp.126-132, 148-150.

(b) Reference 23, esp Chapters 8,9.

34. Nutile, D.A. and Guthrie, A.M. (1979). "Acoustic Shadowing by Seamounts". *J. Acoust. Soc. Am.*, 66, 1813-1817.

35. Hoven, J.M. and Ingram, G.D. (1979). "Viscous Attenuation of Sound in Saturated Sands". *J. Acoust. Soc. Am.*, 66, 1807-1812.

36. Kibblewhite, A.C. and Browning, D.G. (1978). "The Identification of Major Oceanographic Fronts by Long Range Acoustic Propagation Measurements". *Deep Sea Res.*, 25, 1108-1118.

T A B L E 1

MATERIALS RESEARCH LABORATORIES OCEANOGRAPHIC CRUISES
(1975 - 1979)

Code	Date	Region
OP7507	July 1975	Circumnavigation of Tasmania
OP7603	March 1976	Sydney - Auckland (N.Z.)
OP7704	April 1977	Coral Sea (Sydney - Noumea)
OP7803	March 1978	South East Indian Ocean
OP7904	April 1979	Sydney - Wellington (N.Z.)

These cruises represent the principal cruises undertaken for the expressed purpose of collecting physicochemical oceanographic data. Other cruises were undertaken over this period in shallow waters to collect biological information, sediment samples, etc.

TABLE 2

CHARACTERISTICS OF THE DEEP OCEAN SOUND CHANNEL ALONG THE SOFAR AXIS AS DETERMINED FROM MRL CRUISE OP7803 IN THE SOUTH-EAST INDIAN OCEAN, MARCH 1978

Station	Location S/E	Station Depth (m)	Channel Characteristics				
			Depth (m)	Temp (C)	Salin (ppt)	pH	Sound Vel ($m\ sec^{-1}$)
A	29°40'/111°31'	5280	940	4.6	34.5	7.94	1484
B	29°56'/107°18'	5670	925	4.9	34.4	7.96	1485
C	22°58'/105°0'	5200	960	5.1	34.6	7.90	1486
D	17°59'/105°1'	5500	920	5.4	34.7	7.85	1487
E	13°19'/104°59'	6100	950	5.3	34.6	7.81	1487
G	10°15'/110°0'	7700	925	5.3	34.6	7.81	1486
H	14°40'/112°0'	4416	940	5.3	34.6	7.79	1487
J	19°30'/112°0'	2030	>905	5.9	34.6	7.85	1487

TABLE 3

OCEANOGRAPHIC VARIABLES AT VARIOUS SOUND CHANNEL AXIS STATIONS

Ocean Area and Location	Month	Axis Depth (m)	Temp. (^oC)	Salinity ($^o/oo$)	Sound Speed (km sec^{-1})	pH (average)
Atlantic ($30-40^oN$, $50-60^oW$)	Feb.	1320	4.65	35.0	1.492	8.09
Pacific ($30-40^oN$, $150-160^oW$)	March	890	3.72	34.1	1.479	7.70
Baffin Bay ($70-80^oN$, $60-70^oN$)	July	50	-1.49	33.7	1.441	8.02
Mediterranean ($30-40^oN$, $10-20^oE$)	Aug.	150	14.18	38.7	1.511	8.19
Red Sea ($20-30^oN$, $30-40^oE$)	Nov.	190	22.06	40.5	1.537	8.20
Gulf of Aden ($10-20^oN$, $50-60^oE$)	May	300	14.31	35.7	1.511	7.83
Indian Ocean ($10-30^oS$, $105-112^oE$)	March	940	5.1	34.6	1.486	7.84

TABLE 4

COMPARISON OF OBSERVED "EXCESS ABSORPTION FACTORS", $(\alpha\lambda)_{ri}$, AND RELAXATION FREQUENCIES, f_{ri}, FOLLOWING REFERENCES 6, 7, 16

Reaction in Water at Seawater concentrations 1 atm. pressure	f_{ri} (kHz)	$(\alpha\lambda)_{ri}$ (dB)
Boric Acid/Borate		
pH8, 25°C	1.8	
pH8, 4°C	1.0	8.9×10^{-5}
$MgSO_4$ ion pairing	(Mg conc. 12.90×10^{5} μg l^{-1})	
25°C	130	5.53×10^{-4}
4°C	54	5.09×10^{-4}
$MgCO_3$ ion pairing		
pH8, 25°C	29	2.2×10^{-5}
pH8, 4°C	6	

TABLE 5

SUMMARY OF ACOUSTICAL PARAMETERS RELATING TO THE ABSORPTION OF SOUND IN SEAWATER AT THE SOFAR AXIS

α	=	$\Sigma\alpha_i$	
α_i	=	$K_i \dfrac{f_{ri} \quad f^2}{f_{ri}^2 + f^2}$	
$(\alpha\lambda)_{ri}$	=	$\frac{1}{2} K_i v$	
$(\alpha\lambda)_{r1} \times 10^4$	=	$2.69 \times 10^{0.69 \cdot pH - 6}$	dB
f_{r1}	=	$6.1 \times (\frac{S}{35})^{\frac{1}{2}} \times 10^{3 - (1051/T(^{o}K))}$	kHz
$(\alpha\lambda)_{r4} \times 10^4$	=	$2.25 \times 10^{pH - 9}$	dB
f_{r4}	=	$2.82 \times 10^{10 - (2675/T(^{o}K))}$	kHz
$(\alpha\lambda)_{r2} \times 10^4$	$\simeq$	5.09	dB
f_{r2}	=	$1.229 \times 10^{7 - (1483/T)} + 7.5 \times 10^{-2}\ p$	(kHz)
$\alpha 3$	=	$3.0 \times 10^{-4} f^2$	dB/km

TABLE 6

PHYSICOCHEMICAL PROFILE OF A STATION IN THE SOUTH EAST INDIAN OCEAN
(MARCH 1978)

Indian Ocean Cruise
OP7803 (Ref. 2)

Station G
7 March 1978

Sonic Depth 5431 m

Location $10^{\circ}9'S$, $110^{\circ}E$

Depth (m)	Temp. (C)	Salin (ppt)	pH	Vel. (m sec^{-1})
22	29.16	34.25	8.21	1543.3
53	28.32	34.31	8.24	1542.1
92	24.55	34.19	8.16	1533.9
138	20.42	34.42	8.10	1524.2
184	14.07	34.56	8.01	1506.2
276	11.17	34.64	7.86	1498.1
370	10.24	34.81	7.88	1496.5
561	8.38	34.76	7.80	1492.8
753	6.55	34.66	7.78	1488.8
925	5.31	34.65	7.81	1486.6*
1065	4.87	34.68	7.79	1487.2
1320	4.10	34.72	7.82	1488.3
1490	3.76	34.76	7.84	1489.8
1765	3.25	34.76	7.84	1492.3
2245	2.49	34.76	7.86	1497.3
2745	2.09	34.73	7.90	1504.3
3255	1.79	34.73	7.89	1512.0
3780	1.46	34.71	7.90	1520.0

TABLE 7

PHYSICOCHEMICAL PROFILE OF A STATION IN THE TASMAN SEA, OFF TASMANIA, (JUNE 1975)

Tasmanian Cruise
OP7507 (unpubl.)

Station D
25 June 1975

Sonic Depth 2000 m

Location $42^{o}6'S$, $150^{o}E$

Depth (m)	Temp (C)	Salin (ppt)	pH	Vel (m sec^{-1})
0	14.14	35.14	7.83	1504.1
80	13.10	35.17	8.19	1502.0
392	8.94	35.63	7.89	1491.9
1080	6.00	35.42	8.02	1491.7
1290	4.12	35.47	7.99	1487.6*
1770	2.71	35.61	8.30	1489.9

TABLE 8

PHYSICOCHEMICAL PROFILE OF A STATION IN THE CORAL SEA (APRIL 1977)

Coral Sea Cruise
OP7704 (Ref. 1)

Station E
30 April 1977

Sonic Depth: 1800 m

Location 27°S, 161°3'E

Depth (m)	Temp (C)	Salin (ppt)	pH	Vel (m sec^{-1})
17	24.30	35.19	8.20	1533.1
49	24.30	35.37	8.20	1533.8
99	21.90	35.21	8.18	1528.4
193	19.19	35.90?	8.13	1523.4
296	17.52	35.24	8.12	1519.5
491	13.03	34.74	8.05	1508.1
686	8.93	34.42	7.98	1496.5
986	5.72	34.17	7.98	1488.7
1293	4.14	34.21	7.86	1487.4*
1487	3.48	34.59	7.86	1488.4

T A B L E 9

CHARACTERISTICS OF THE DEEP OCEAN SOUND CHANNEL ALONG THE SOFAR AXIS AS DETERMINED FROM MRL CRUISE OP7803 IN THE SOUTH EAST INDIAN OCEAN (REF. 2), MARCH 1978

Station	Location S/E	Station Depth (m)	Channel Characteristics: Depth (m)	Temp (C)	Salin (ppt)	pH	Sound Vel (m sec^{-1})
A	$29^{o}40'/111^{o}31'$	5280	940	4.6	34.5	7.94	1484
B	$26^{o}56'/107^{o}18'$	5670	925	4.9	34.4	7.96	1485
C	$22^{o}58'/105^{o}0'$	5200	960	5.1	34.6	7.90	1486
D	$17^{o}59'/105^{o}1'$	5500	920	5.4	34.7	7.85	1487
E	$13^{o}19'/104^{o}59'$	6100	950	5.3	34.6	7.81	1487
F	$09^{o}01'/104^{o}59'$	5666	1175?	4.7	34.8	7.80	1489
G	$10^{o}15'/110^{o}0'$	7700	925	5.3	34.6	7.81	1486
H	$14^{o}40'/112^{o}0'$	4416	940	5.3	34.6	7.79	1487
J	$19^{o}30'/112^{o}0'$	2030	>905	5.9	34.6	7.85	1487
K	$24^{o}0'/112^{o}0'$	960	too shallow				
L	$29^{o}0'/113^{o}31'$	1120					

TABLE 10

CHARACTERISTICS OF THE DEEP OCEAN SOUND CHANNEL ALONG THE SOFAR AXIS COMPUTED FROM DATA FROM MRL CRUISE OP77004 IN THE CORAL SEA, MAY 1977

Station	Location S/E	Station Depth (m)	Channel Characteristics Depth (m)	Temp (C)	Salin (ppt)	pH	Sound Vel (m sec^{-1})
A	$31^{\circ}60'/153^{\circ}60'$	4800	> 1270	4.70	34.49	7.95	1489
D	$29^{\circ}6'/158^{\circ}36'$	3300	*ca.* 1430	3.70	34.60	7.88	1488
E	$27^{\circ}00'/161^{\circ}4'$	1800	1293	4.14	34.21	7.86	1487
F	$25^{\circ}00'/163^{\circ}28'$	1800	*ca.* 1140	4.45	34.50	7.86	1487
G	$23^{\circ}40'/165^{\circ}6'$	3600	> 1128	4.59	34.70	7.86	1487
			< 1300	3.98	34.43	7.87	1487
H	$22^{\circ}34'/166^{\circ}10'$	2700	926	5.19	34.33	7.86	1486
J	$22^{\circ}42'/163^{\circ}22'$	2100	953	5.21	34.46	7.94	1486
K	$22^{\circ}57'/160^{\circ}00'$	2400	981	5.10	34.49	7.93	1486
L	$24^{\circ}19'/155^{\circ}44'$	4015	1259	4.25	34.52	7.89	1488
M	$25^{\circ}5'/155^{\circ}0'$	780		too shallow			

TABLE 11

CHARACTERISTICS OF THE DEEP OCEAN SOUND CHANNEL ALONG THE SOFAR AXIS COMPUTED FROM DATA FROM MRL CRUISE OP7507 AROUND TASMANIA, JULY 1975 (REF.3)

Station	Location S/E	Station Depth (m)	Channel Characteristics: Depth (m)	Temp (C)	Salin (ppt)	pH	Sound Vel (m sec^{-1})
A	40°46'/146°32'	100		too shallow			
D	43°10'/149°58'	2000	1290	4.12	34.47	7.99	1487
E	45°58'/147°44'	2000	⩾ 1100	4.52	34.44	7.99	1486
F	43°32'/148°20'	1700	> 998	5.01	34.42	8.06	1486
			< 1498	2.97	34.59	7.94	1486
H	46°00'/145°00'	2100	> 989	5.03	34.53	7.89	1486
			< 1488	3.06	34.71	7.89	1486
K	41°43'/143°43'	3600	> 1000	4.88	34.39	7.95	1486
			< 1500	2.79	34.80	7.88	1486
Averaged Channel Characteristics			*ca.* 1260	4.0	34.54	7.95	1486

TABLE 12

PHYSICOCHEMICAL AND ACOUSTICAL PROPERTIES OF THE DEEP OCEAN SOUND CHANNEL IN WATERS AROUND AUSTRALIA

MRL Cruise	OP7803	OP7704	OP7507
Location	Indian Ocean	Coral Sea	Tasmania
Date	March 1978	May 1977	July 1975
Averaged Channel Characteristics			
Depth (m)	940	1270	1260
Temp (^{o}C)	5.1	4.2	4.0
Salinity (ppt)	34.6	34.5	34.5
pH	7.84	7.88	7.95
Sound Vel. (m sec^{-1})	1486	1487	1486
$(\alpha\lambda)_{r1} \times 10^4$ (dB)	0.69	0.74	0.82
f_{r1} (kHz)	1.02	0.98	0.98
$(\alpha\lambda)_{r4} \times 10^4$ (dB)	0.16	0.17	0.20
f_{r4} (kHz)	6.9	6.4	6.31
$(\alpha\lambda)_{r2} \times 10^4$ (dB)	4.9	4.8	5.0
f_{r2} (kHz)	64.7	64.9	64.3
α_3 (dB km^{-1})	$3.0 \times 10^{-4} f^2$	$3.0 \times 10^{-4} f^2$	$3.0 \times 10^{-4} f^2$

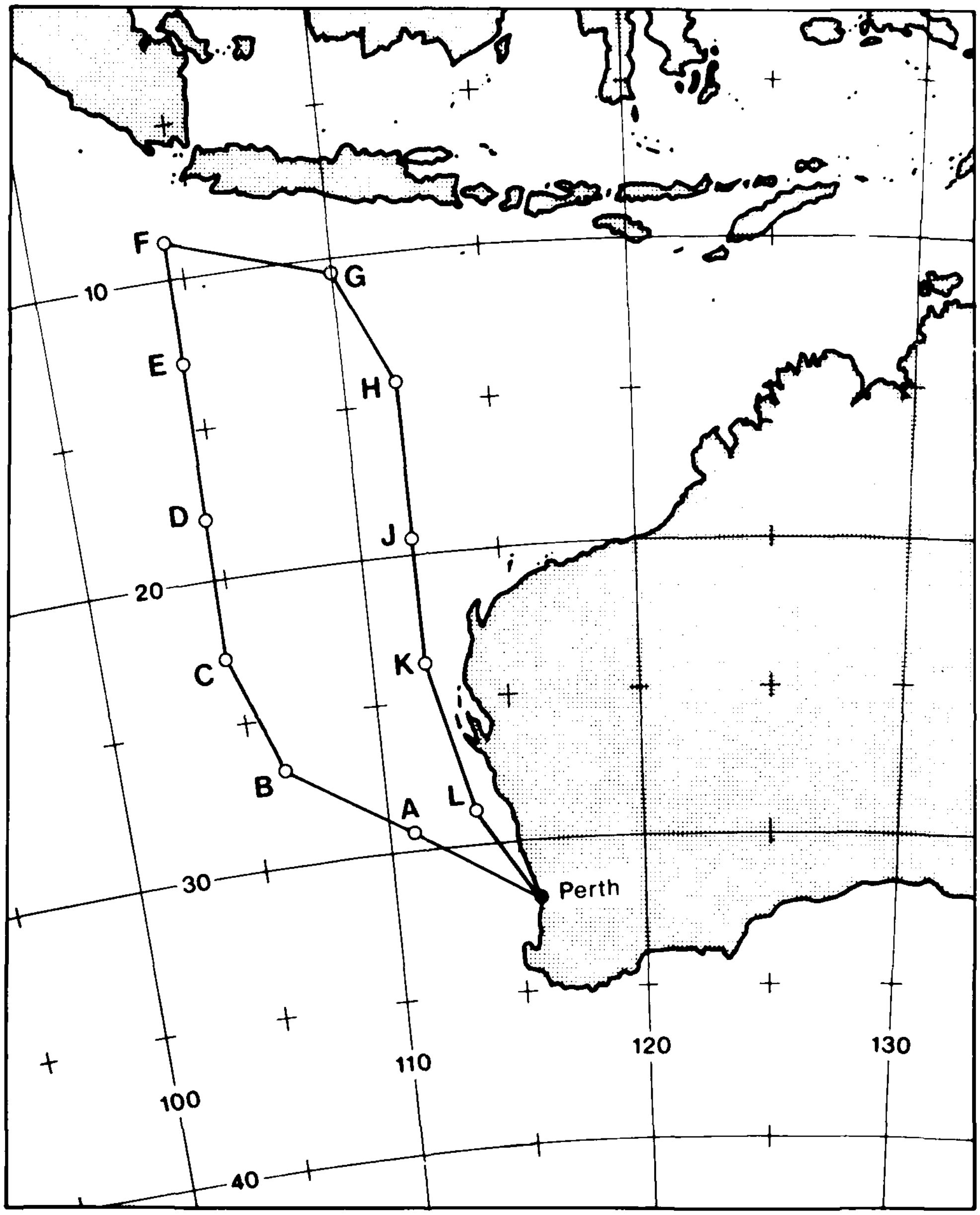

FIG. 1 - Course of MEG Oceanographic Cruise, OP7803,
carried out on board HMAS Diamantina
(February-March 1978).

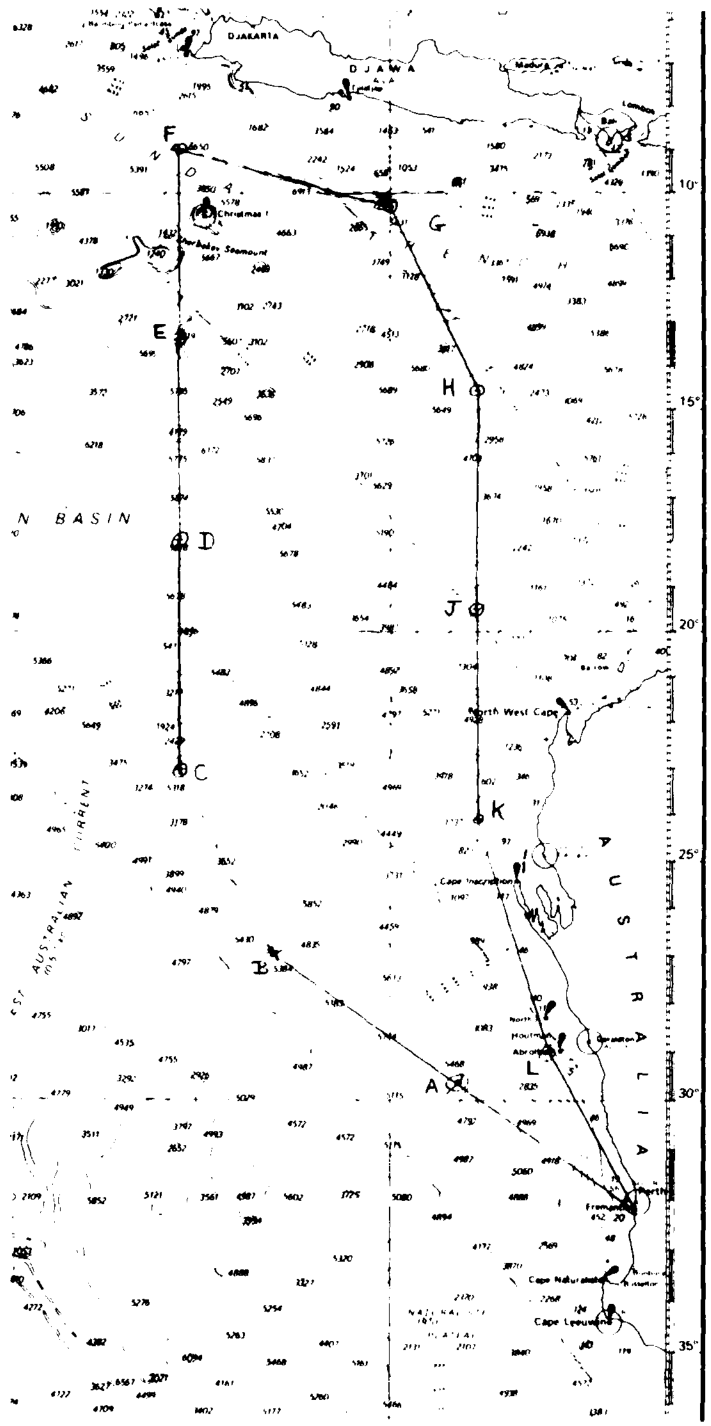

FIG. 2 - Detailed Section of International Chart Series: Southern Indian Ocean (AUS 4070), covering the course traversed in MEG Oceanographic Cruise, OP7803. Reproduced with permission of The Hydrographer, Royal Australian Navy.

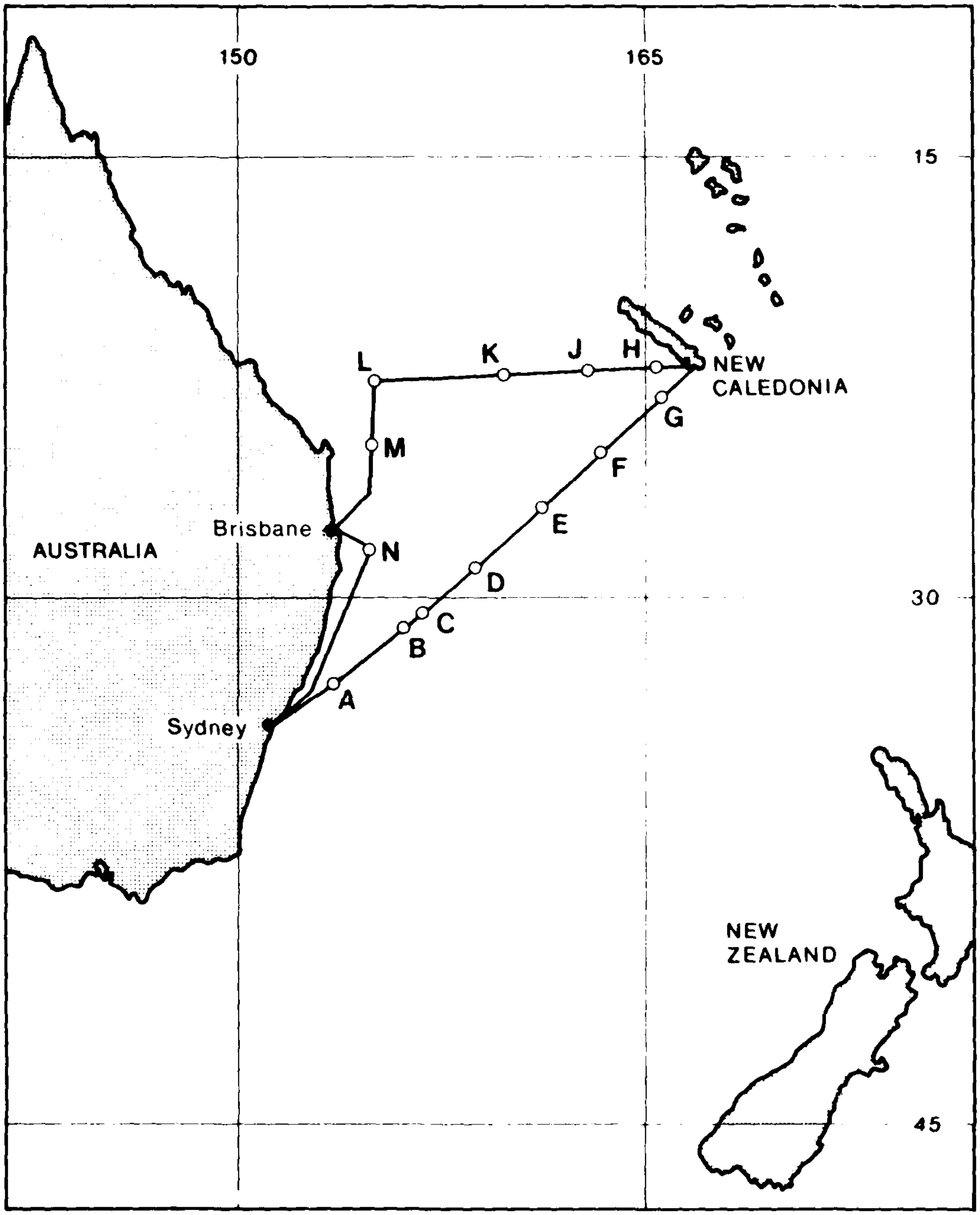

FIG. 3 - Course of MEG Oceanographic Cruise, OP7704, carried out on board HMAS Kimbla, April-May 1977.

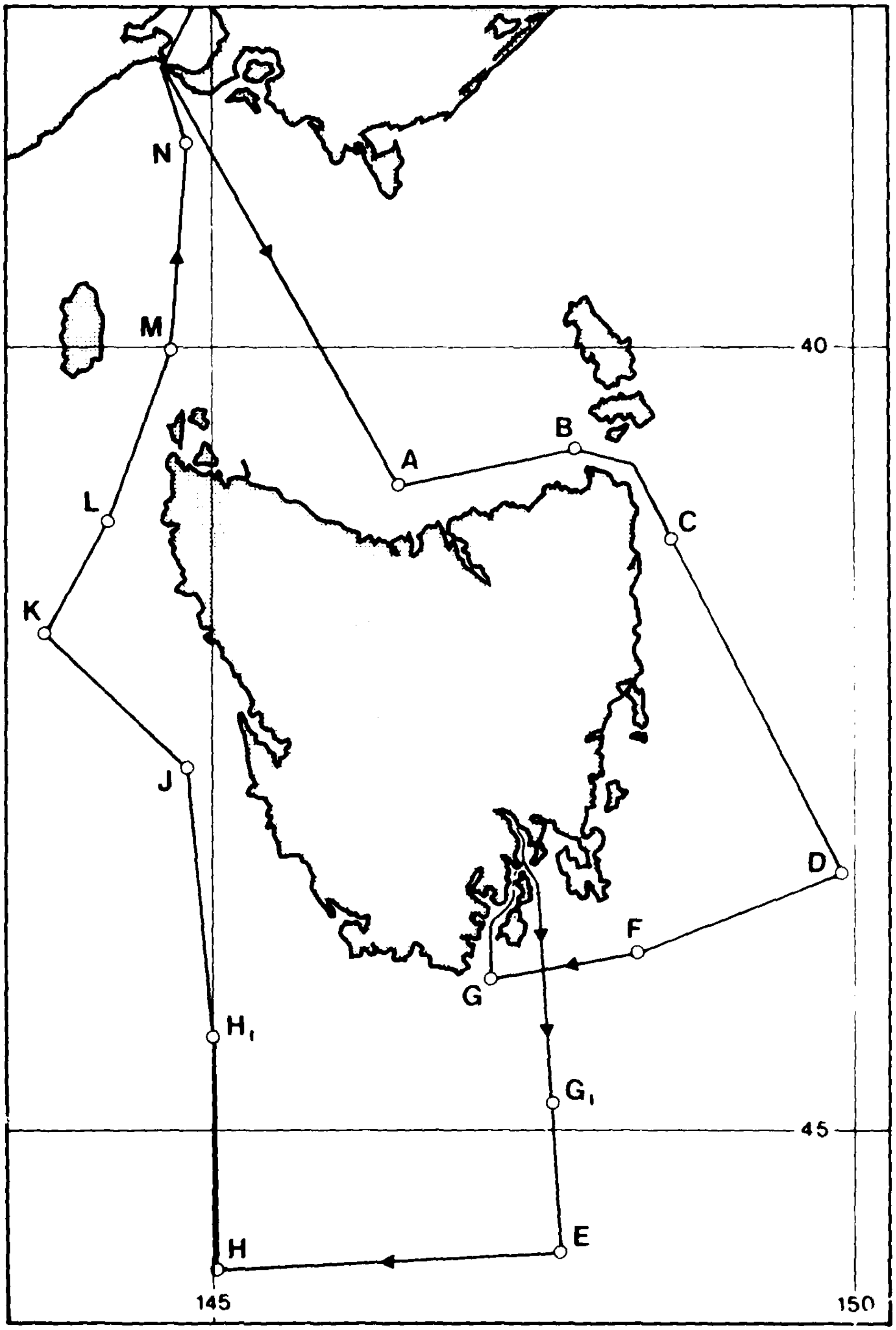

FIG. 4 - Course of MEG Oceanographic Cruise, OP7507, carried out on board HMAS Diamantina, July 1975. The deep water stations occurred at D, E, F, H and K.

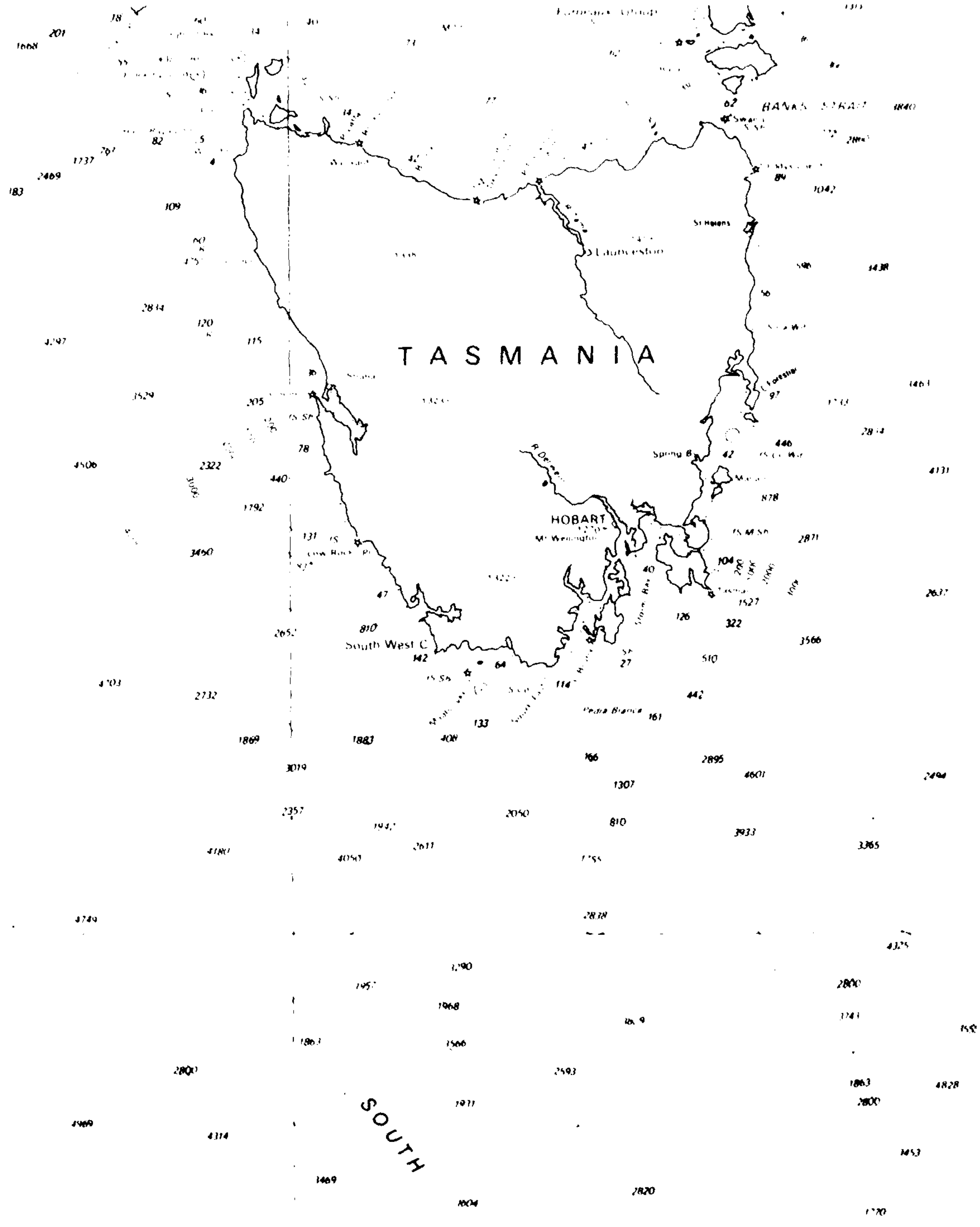

FIG. 5 - Detailed Section of International Chart Series: South Pacific Ocean, New Zealand to S.E. Australia (Int. 601, NZ 4601), covering course traversed in MEG Oceanographic Cruise, OP7507. Reproduced with permission of The Hydrographer, Royal Australian Navy.

DISTRIBUTION LIST

MATERIALS RESEARCH LABORATORIES

Chief Superintendent
Superintendent, Physical Chemistry Division
Mr J.H. Bishop
Dr D.J. Whelan
Library
Librarian, Materials Testing Laboratories, NSW Branch
(Through Officer-in-Charge)

DEPARTMENT OF DEFENCE

Chief Defence Scientist
Deputy Chief Defence Scientist
Controller, Projects and Analytical Studies
Controller, Service Laboratories and Trials
Army Scientific Adviser
Air Force Scientific Adviser
Navy Scientific Adviser
Chief Superintendent, Aeronautical Research Laboratories
Chief Superintendent, Weapons Systems Research Laboratory, Defence Research Centre
Chief Superintendent, Electronics Research Laboratory, Defence Research Centre
Chief Superintendent, Advanced Engineering Laboratory, Defence Research Centre
Superintendent, Trials Resources Laboratory, Defence Research Centre
Deputy Director, Scientific and Technical Intelligence, Joint Intelligence Organisation
Head, Engineering Development Establishment
Librarian, Bridges Library, Royal Military College
Officer-in-Charge, Document Exchange Centre (16 copies)
Superintendent, Services Research Laboratories
Superintendent, Propulsion and Marine Physics
Hydrographer, RAN
Assistant Secretary, Defence Facilities Policy and Development
Officer-in-Charge, RANTAU
Director, Naval Quality Assurance
Director, Fleet Maintenance
Director, Naval Use Requirements
Director, Naval Ship Design
Project Director, Base Development
Director, Trials
Controller Publications - Navy
Chief of Naval Technical Services
Senior Librarian, Defence Research Centre
Librarian, RAN Research Laboratory
Technical Reports Centre, Defence Central Library
Central Office, Directorate of Quality Assurance - Air Force

DISTRIBUTION LIST

(continued)

DEPARTMENT OF PRODUCTIVITY

NASA Canberra Office
Head of Staff, British Defence Research and Supply Staff (Aust.)

OTHER FEDERAL AND STATE DEPARTMENTS AND INSTRUMENTALITIES

The Chief Librarian, Central Library, CSIRO
Australian Atomic Energy Commission Research Establishment
The Librarian, National Measurement Laboratory, CSIRO
Chief, Division of Chemical Physics, CSIRO
The Librarian, Division of Fisheries and Oceanography, CSIRO
The Librarian, Australian Institute of Marine Science
Ministry of Conservation
The Executive Director, Victorian Institute of Marine Science
Prof B.R. Morton, Department of Mathematics, Monash University
Dr I.D. Rae, Chemistry Department, Monash University
Marine Chemistry Section, School of Chemistry, University of Melbourne
Dr T.A. O'Donnell, Chemistry Department, University of Melbourne
Dr R.B. Johns, Chemistry Department, University of Melbourne

MISCELLANEOUS - AUSTRALIA

Editor, "Search", Science House
Secretary, Department of Science

MISCELLANEOUS - OVERSEAS

Defence Scientific and Technical Representative, Australian High Commission, Australia House, London, England
Assistant Director/Armour and Materials, Military Vehicles and Engineering Establishment, Surrey, England
Reports Centre, Directorate of Materials Aviation, Kent, England
Library - Exchange Desk, National Bureau of Standards, Washington, USA
US Army Standardization Representative, C/o DGAD (NSO), Canberra, ACT
The Director, Defence Scientific Information and Documentation Centre, Delhi, India
Colonel B.C. Joshi, Military, Naval and Air Adviser, High Commission of India, Red Hill, ACT
Director, Defence Research Centre, Kuala Lumpur, Malaysia
Exchange Section, British Library, Lending Division, Yorkshire, England
Periodicals Recording Section, Science Reference Library, The British Library, Holborn Branch, London, England

DISTRIBUTION LIST

(continued)

MISCELLANEOUS - OVERSEAS (Cont.)

Library, Chemical Abstracts Service, Ohio, USA
INSPEC: Acquisition Section, Institution of Electrical Engineers, Herts, England
Overseas Reports Section, Defence Research Information Centre, Kent, England
Counsellor Defence Science, Washington DC, USA (Attention: Dr J. Stals)
Engineering Societies Library, New York, USA
Director, National Physical Laboratory, Middlesex, England
The Librarian, Battelle Memorial Institute, Ohio, USA
Director General, Defence Research Establishment Ottawa, Ontario, Canada
Director General, Defence Research Establishment Toronto, Ontario, Canada
Director General, Defence Research Establishment Atlantic, Nova Scotia, Canada
Director General, Defence Research Establishment Pacific, British Columbia, Canada
Science Information Division, Department of Scientific and Industrial Research, Wellington, New Zealand
Librarian, Auckland Industrial Development Division, Department of Scientific and Industrial Research, Auckland, New Zealand
Dr F. Richards, Department of Oceanography, University of Washington, Washington, USA
Dr L.D. Hampton, Applied Research Laboratories, The University of Texas, Texas, USA
Dr H. Medwin, Physics and Chemistry Department, Naval Postgraduate School, California, USA
Dr D. Browning, Physics Department, Naval Postgraduate School, Monterey, USA
Dr J. Northrop, Naval Undersea Centre, San Diego, USA
Dr J. Lovett, Environmental Acoustics Division, Naval Ocean Systems Centre, San Diego, USA
Dr R.H. Johnson, Hawaii Institute of Geophysics, University of Hawaii, Hawaii, USA
Dr W.F. Forbes, Department of Statistics, University of Waterloo, Ontario, Canada
Dr R.H. Mellen, New London Laboratory, Naval Underwater Systems Centre, Connecticut, USA
Dr V.P. Simmons, Defence Advanced Research Projects Agency, Virginia, USA
Dr H. Box, Roswell Park Memorial Institute, New York, USA
Prof F.A. Richards, C/- Office of Naval Research, American Embassy, Tokyo, Japan (2 copies)
Drs M. Schulkin and H.W. Marsh, Applied Physics Laboratory, University of Washington, Washington, USA

DISTRIBUTION LIST

(continued)

MISCELLANEOUS - OVERSEAS (Cont.)

Dr R.N. Denham, Defence Science Establishment, Auckland, NZ
Dr A.C. Kibblewhite, Department of Physics, University of Auckland, Auckland, New Zealand
Dr F.H. Fisher, University of California (San Diego), Marine Physical Laboratory, Scripps Institute of Oceanography, San Diego, USA
The Executive Director, AMSTAC, Department of Science, Canberra, ACT
Dr J. Riley, Department of Oceanography, University of Liverpool, Liverpool, England
Dr G. Jackson, Central Dockyard Laboratory, HM Naval Base, Portsmouth, UK
The Director, National Institute of Oceanographic Sciences, Surrey, England
Naval Ship R & D Centre, Annapolis, USA (Attention: Dr H. Preiser and Dr E. Fischer)
Central Dockyard Laboratory, HM Naval Base, Portsmouth, UK (Attention: Dr D. Houghton)
Naval Research Laboratory, Washington, USA (Attention: Dr R.R. Rojas)
Naval Undersea Center, San Diego, USA (Attention: Dr D.E. Andrews, Jnr.)
Scripps Institute of Oceanography, La Jolla, USA (Attention: Dr E. Goldberg)
Woods Hole Oceanographic Institution, Woods Hole, Mass., USA (Attention: Dr P.G. Brewer)
Biologische Anstalt Helgoland, Hamburg, West Germany (Attention: Dr O. Kinne)
Oceanography Division, St. Louis, USA (Attention: Mr A. Pressman, Code 330)
Laboratorio de Ensayo de Materiales e Investigaciones Tecnologicas, Argentina (Attention: Dr V. Rascio)
Department of Zoology, National Science Museum, Tokyo, Japan (Attention: Dr S. Mawatari)
Department of Oceanography, University of Southampton, UK (Attention: Dr J.D. Burton)
Department of Oceanography, University of Liverpool, UK (Attention: Dr J. Riley)
National Institute of Oceanographic Sciences, Surrey, UK (Attention: Dr Culkin)
Miami Marine Research Inc., Florida, USA (Attention: Dr S. Miller)
Defence Research Establishment Pacific (DREP), Canada (Attention: Mr J. Carson)

DISTRIBUTION LIST

(continued)

MISCELLANEOUS - OVERSEAS (Cont.)

Marine Science Laboratories, North Wales, UK
(Attention: Dr Crispe)
Scottish Marine Biological Association Laboratory, Scotland
(Attention: Dr H. Barnes)
Centre ORSTOM, B.P. No. A5, Noumea, New Caledonia
(Attention: Dr J.R. Donguy)
US Environmental Protection Agency, West Kingston, USA
Fisheries Research Board of Canada, Marine Ecology Laboratory,
Bedford Institute, Dartmouth, Canada
(Attention: Dr I. Duedall)
Graduate School of Oceanography, University of Rhode Island, USA
(Attention: Dr D.R. Kester)
Defence Scientific Establishment, HMNZ Naval Dockyard, NZ
(Attention: Dr D. Barnes)
Secretariat General, Comite International Permanent pour la,
France
Department of Biological Sciences, Portsmouth Polytechnic, England
(Attention: Dr A. Chamberlain)

DATE

ILMED

8